UNCLASSIFIED

AD NUMBER
AD810589
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 30 MAR 1967. Other requests shall be referred to Air Force Technical Applications Center, Washington, DC.**
AUTHORITY
AFTAC ltr 28 Feb 1972

THIS PAGE IS UNCLASSIFIED

DESIGN, TEST, AND EVALUATION OF PRE-SET BANDPASS FILTERS

30 MARCH 1967

Prepared For

AIR FORCE TECHNICAL APPLICATIONS CENTER
Washington, D. C.

By

Robert L. Sax
TELEDYNE INC.

Under

Project VELA UNIFORM

Sponsored By

ADVANCED RESEARCH PROJECTS AGENCY
Nuclear Test Detection Office
ARPA Order No. 624

DESIGN, TEST AND EVALUATION OF PRE-SET BANDPASS FILTERS

SEISMIC DATA LABORATORY REPORT NO. 176

AFTAC Project No.:	VELA T/6702
Project Title:	Seismic Data Laboratory
ARPA Order No.:	624
ARPA Program Code No.:	5810
Name of Contractor:	TELEDYNE, INC.
Contract No.:	F 33657-67-C-1313
Date of Contract:	3 March 1967
Amount of Contract:	$ 1,735,617
Contract Expiration Date:	2 March 1968
Project Manager:	William C. Dean (703) 836-7644

P. O. Box 334, Alexandria, Virginia

AVAILABILITY

This research was supported by the Advanced Research Projects Agency, Nuclear Test Detection Office, under Project VELA-UNIFORM and accomplished under the technical direction of the Air Force Technical Applications Center under Contract F 33657-67-C-1313.

Neither the Advanced Research Projects Agency nor the Air Force Technical Applications Center will be responsible for information contained herein which may have been supplied by other organizations or contractors, and this document is subject to later revision as may be necessary.

TABLE OF CONTENTS

		Page No.
	ABSTRACT	
1.	INTRODUCTION	1
2.	GENERATION OF NOISE AND SIGNAL TEST DATA	2
3.	VISUAL DISPLAY OF TEST DATA	3
4.	PERFORMANCE ANALYSIS PARAMETERS	4
5.	DESCRIPTION OF FILTERS	5
	A. Phaseless High Pass Filter	6
	B. Gapped Finite Difference Filter	7
6.	RESULTS	8
7.	CONCLUSIONS	11

ABSTRACT

Using a known signal added to Gaussian noise, we evaluate the performance of several bandpass filters. The results are about the same as previous excercises carried out on real data. The gain in threshold for reliable detection and gain in S/N ratio is approximately 8-9 db for a bandpass filter which suppresses both the .2 cps and 2 cps peaks but considerably less if a strong 2 cps peak is not suppressed.

1. INTRODUCTION

The design of a bandpass filter is necessarily an art. The teleseismic signal is an a-priori unknown narrow band transient expected to occur between .7 and 2 cps. Although some ambient noise samples are demonstrably stationary Gaussian on a time scale of approximately three hours, the noise power can vary markedly between day and night, seasonably, and is occasionally subject to extreme spatial or temporal variations in the microseism and 2 cps peaks.

In designing the filter, the following ground rules were taken as guides.

(1) Both a .2 cps and 2 cps peak are present in the noise with the .2 cps peak nominally 25 times the power of the 2 cps peak. As minimum occurs in the signal band at 1.5 cps which is down by 100 in power from the .2 cps peak. The noise is modeled as a stationary and Gaussian process, in order that performance of filters can be evaluated with a test of about 10 samples, otherwise a much larger sample population and higher moments must be considered in evaluating test data.

(2) The filter must have a stable approximate inverse in order that most of the signal distortion caused by the filter can be corrected.

(3) Since the filter is to be used on each channel prior to array processing, the filter should be fast enough that the data

processing time is not more than a small fraction (10%) of real time per data channel. Neither the filters nor their inverses should require more than several multiplications per point.

2. GENERATION OF NOISE AND SIGNAL TEST DATA

The noise is obtained from a pseudo random number generating function, FORTRAN 63 RANF(-1). The algorithm has been tested and shown statistically to provide a sequence of random uncorrelated numbers. The sequence will not repeat until millions of samples have been called. The pseudo random numbers are averaged nine times to produce a nearly Gaussian input of uncorrelated samples. They are filtered twice in series using RECFIL3, a recursive narrow-band filter. The low frequency noise component is obtained with the frequency set at to .2 cps and $Q = fo/\Delta f = 3.5$ and with a 12 db/octave high and low frequency cutoff, and the high frequency to 2.0 cps, $Q = 6$, and 6 db/octave. This will result approximately in noise with the spectral power characteristics described in the introduction. A plot of the power spectral density of a sample of the synthetic noise is shown in Figure 1.

To generate a signal, the displacement potential is taken as an impulse into a system which models linear creep by a dashpot and spring in series. The particle velocity output of the system is the second derivative of the reduced displacement potential which can be approximated by an impulse far from the source (or a step function close to the source). Conceivably, the number of spring dashpot units we pass the signal through is proportional to the time spent in propagating through the medium.

The subroutine used to generate the synthetic signal is called SIG. The number of spring dashpot units is a parameter in the program which was arbitrarily set to 100 for modeling teleseismic signals. This resulted in wavelets similar to Ricker wavelets which appeared as a suitable model for a teleseismic signal. With another parameter we set the peak frequency of the wavelet. Further, to model a shallow contained explosion source we add a surface pP reflection with a delay of 0.7 seconds. A high frequency signal is modeled with an apparent frequency of 1.8 cps and low frequency signal with an apparent frequency of 1 cps. The tests for evaluating filters were applied to both the high and low frequency signals to demonstrate the robustness of the results. The noise, the wavelet, and echo generating subroutines were incorporated into a single subroutine called SYNSEI which outputs the wavelet, wavelet + echo, noise, and the wavelet + echo + noise. It is only necessary to call SYNSEI to generate a channel of data, and if desired, the user can save the wavelet, noise, etc., for future S/N computations.

3. VISUAL DISPLAY OF TEST DATA

As many as 14 plots can be legibly displayed on a single page using the CAL COMP plotter. A program, TEST, was written which takes the plot parameters, data sample rate, and total number of points on the record as fixed parameters. Case cards specifying data parameters are read until the end of card file. A set of 13 different signal noise ratios are read in as sequential input to the subroutine SYNSEI. After generating data for each prescribed input S/N (standard deviation of signal/standard deviation of noise), the program will execute a sub-program which operates on the data. A plot file is generated with the first channel showing the signal without noise. The following channels start with the highest input S/N ratios and end with the lowest. For each case card, up to six different sub-programs can be run on the test data, each resulting in a plot file. For example, six different filter designs can be run and plot per case card. A 14-channel plot of records is obtained for each processor with input S/N varying from 24 db to -2 db.

4. PERFORMANCE ANALYSIS PARAMETERS

The program TEST can also be used to summarize performance measurements and evaluations for any desired number of identical signals added to independent noise samples. For example, to evaluate the band-pass filters, ten different noise samples were run at each of the 13 input S/N levels. The output S/N ratio is then computed in exactly the same way as the input S/N ratio. For the signal, the standard deviation was measured in a 1 second exponentially tapered time window. For noise a one-minute sample was used.

Another measure of performance was to compare the absolute maximum of the time series occurring in the 30-seconds of noise taken in front of the starting point of the signal to the absolute maximum on the whole one-minute record. Both the magnitude of the ratio and the location of the maximum are listed. If the detected absolute maximum is located under a signal peak or trough, we score the pick as a successful detection of the signal; if the maximum is located under noise, we score the pick as a failure. The reliable detection threshold is defined as the S/N above which in all ten trials all of the picks are successful. The number of successful picks is listed as a function of input S/N ratio. At each input S/N ratio above the reliable detection threshold is a list of the average output peak ratio. Estimates of the 95% confidence interval (the mean $\pm$ interval is expected to contain 95% of the samples) are included with all of the performance measurements.

5. DESCRIPTION OF FILTERS

The program TEST was used to visually display samples of filtered data. After visual examination of a number of different filters, good results were observed for a 2-pole phaseless high pass filter set with the 3 db point at 1 cps; and also with a second order gapped finite difference operator with the first spectral peak at 1.1 cps, and the first null at 2.2 cps. The phaseless high pass filter only suppresses the .2 cps peak in the noise. The finite difference operator suppresses both the .2 cps and 2 cps noise peak. The phaseless highpass filter produced no visible distortion of any of the signals including the first motion, whereas the finite difference operator produced only slight distortion in the 1 cps signal but introduced considerable distortion in the 1.8 cps signal as expected due to its proximity to the 2.2 cps null of the filter. In accordance with the stated ground rules both filters have an approximately stable inverse so that almost all distortion introduced by filtering can be removed after multi-channel array processing of the signal + noise. These two filters were selected for further evaluation of performance.

A. Phaseless High Pass Filter

The Laplace transform of the single pole low pass filter is $p(s) = \frac{\alpha}{s + \alpha}$, and the high pass filter $q(s) = \frac{s}{s + \alpha}$. As an approximation with less than 10% error up to one-third of the folding frequency,

$$s = 1 - z, \text{ where } z = \prime^{s} .$$

Taking the z transform of the data a D(z) and the filtered output as F(z), with S.R. = sampling rate,

$$F(z)\left[(1 + \beta) - z\right] = D(z),\ \beta = \frac{\alpha}{\pi\ S.R.} = \frac{2\ Fo}{S.R.}$$

$$F_i = \left(\frac{\beta}{1 + \beta}\right) D_i + \left(\frac{1}{1 + \beta}\right) F_{i-1},\ F_o = 0$$

The high pass filter is obtained as $H_i = D_i - F_i$.

The recursive low pass filter involves two multiplication per data point; and the high pass filter, one multiplication per point.

$$H_i = \left(\frac{1}{1 + \beta}\right)\left(H_{i-1} + D_i - D_{i-1}\right),\ H_o = 0$$

The 2-pole high or low pass filter can be obtained by reversing the previous output, filtering again, and reversing the new output. Equivalently by transforming the index,

$$H_k^1 = \frac{1}{1+B}\ (H_{k-1}^1 + H_k - H_{k-1})\quad k\text{-}N\text{-}i+1 \quad i=2,\dots,N$$

The recursive phaseless 2-pole high pass filter takes two multiplications per data point. The inverse of the single pole high pass filter is

$$H_i = (1 + \beta)\ H_i^1 - H_{i-1}^1 + H_{i-1}$$

It is obtained with one multiplication per point. For the inverse of the two-pole phaseless operator, the one-pole output is reversed, filtered again, and the output is reversed; or by transforming the index,

$$k = N - i + 1 \qquad i = 2, \ldots . N$$

$$D_k = (1 + \beta) H_k - H_{k-1} + D_{k-1}$$

B. Gapped Finite Difference Filter

The gapped difference operator is given as $\{1, 0, 0 \ldots, 0, -k\}$, where $k \leq 1$, and the gap is specified by the number of points between 1 and k. That which is considered here is given by $k = 1$. The spectrum of the operator is given by

$$D(f) = i \sin \left(\frac{\pi f}{2 fo} \right)$$

where the frequency of the first peak of the filter is related to the number of points in the gap, L .

$$L = \frac{S.R.}{2 fo} \qquad \text{S.R., the sampling rate}$$

Note that series application of D(f) can be used to generate higher differences

$$D^{(m)} (fo) = (i^2)^{\frac{m}{2}} = (-1)^n = D^{2n} (f_o)$$

where $n = 1, 2, 2, \ldots$ specifies the 2nd difference, 4th difference, etc. Taken as a filter we observe that for N = odd, the sign of the filter is reversed. The response of the filter is

$$D^{(2n)} (f) = (-1)^n \sin^{2n} \left(\frac{\pi f}{2 fo}\right)$$

The gap, L, is determined by setting the first peak to the desired frequency. Nulls occur at integer multiples of twice the frequency of the first peak, and additional peaks occur at frequencies between the null's. Suppose at frequencies greater than the first null in the spectrum for example at f = 2 fo, the signal and noise power are expected to attenuate rapidly with increasing frequency. These high frequency peaks will in this case produce negligible effects in the filtered output. If, however, we wish to insure attenuation of high frequency peaks in the noise spectrum we may apply in series with the filter a low pass smoothing operator $\{1, o, o, \ldots, o, +k\}$ where $k \leq 1$. The spectrum of the operator is given by S(f).

$$S(f) = \cos\left(\frac{\pi}{2}\frac{f}{fo}\right)$$

Repeated application of the smoothing operator leads to the operator

$$S^{(m)}(f) = \cos^{m}\left(\frac{\pi}{2}\frac{f}{fo}\right)$$

where, for example, fo may be taken at the folding frequency.

For k = 1 there are no multiplications in either the smoothing or difference operator, so that the above digital operators are exceedingly fast. For k = 1 only an approximate inverse can be obtained. These are, in fact, simply deghosting operators. For $k \leq 1$, exact inverses can be obtained. The inverses can be designed as recursive filters and require n multiplications per point wher n is the number of series applications of $D^{(n)}$ or $S^{(n)}$.

6. RESULTS

Figure 1 shows the spectrum of the noise used for the tests.

Figure 2 shows the low frequency signal with apparent frequency of 1 cps. The next thirteen channels show the same signal added with different gains to different noise samples with the same power spectrum. The input S/N ratio in decibels is listed on the left of each channel. Figure 3 shows a similar visual display of the signal passed through a high pass filter. Since the noise spectrum above 3 cps attenuates at 18 db/octave, the response to this filter is not substantially different from a bandpass filter with the high frequency cutoff above 3 cps. The low frequency cutoff of 12 db/octave is 3 db down at 1 cps. The slight relative amplification of the 2 cps peak is approximately 3 db. This could be eliminated at the cost of two mutliplications per point (or at double the computation time) by a 4-pole high pass filter with 3 db point at 0.5 cps as for example with the SDL filter. Comparing Figure 2 with Figure 3, no significant distortion of signal shape is observed. The filter may enhance first motion slightly by reducing the low frequency noise component. Figure 4 displays the gapped second finite difference filter which is designed to attenuate both the .2 cps microseism peak and 2 cps peak. By comparing Figure 2 with Figure 4 and Figure 5 with Figure 7 considerable improvement can be observed in apparent detection based on peak amplitude or peak-to-peak down to -2 db. Since the 2 cps peak is close to the signal band, its suppression results in considerably more signal distortion. The filter could be useful both as a pre-array processor and for simple detection. If undistorted measurement and display of the signal is desired after array processing, distortion can be removed by inverse filtering of the array output.

Figures 5, 6 and 7 are the same operations as 2, 3 and 4, respectively, except that the test signal is nearly an octave higher in apparent frequency. The same observations can be made with the high frequency signal as previously pointed out for the low frequency signal indicating the robustness of the results; that is, the results do not depend on the exact signal waveform or noise spectrum.

Tables 1, 2 and 3 are summaries of performance parameters derived from ten noise samples added to each signal held at fixed gain or for fixed S/N ratio. Each input S/N ratio was the same as that shown on the displays of a single sample. It is listed on the left-hand column of each table. Since we can observe the filtered signal alone and the filtered noise alone, we can compute the output S/N ratio for comparison with the input S/N ratio. From tables we observe a gain of 4 to 5 db for the high pass filter and 8 to 9 db for the gapped second difference filter. Another test was designed to gauge the performance of the filter based on measurements of the signal plus noise. The detection score lists the number of detection successes out of a possible score of ten. A success is indicated if the signal is the largest event on a one-minute record. The detection threshold is defined as the S/N ratio above which the detection probability is indicted as one; where a failure is not observed in fifty adjacent one-second time windows. Without filtering, this threshold is observed on Table 1 at input S/N of 7.5 db; with the high pass filter, the threshold drops to an input S/N of 4.5 - 6 db; and with the gapped second difference operator, it drops to an input S/N of 0 db.

In all the filtered cases, the reliable threshold output S/N ratio was given as 8 to 10 db.

For all S/N ratios above the reliable detection threshold, the output peak of the signal was compared to the output peak of 30-seconds of noise. The ratio in db is shown in Tables 1, 2 and 3. The value of this parameter at the reliable detection threshold is in all cases from 4 to 5 db. The difference between the output S/N ratio and output peak ratio is 5.5 db to within approximately $\pm$ 1 db for all of the filtered data; and 3 db for the unfiltered data.

7. CONCLUSIONS

The gapped second difference filter appears to yield the best performance as a simple detector. The indicated gain in S/N ratio of 8.5 db and gain in threshold of 7.5 db are compared with the high pass filter's performance of 3.5 db and 2.5 db, respectively. One of the keys to optimum selection of band pass filters appears to involve the suppression of spectral peaks occurring in the noise spectrum, especially the 0.2 cps and 2.0 cps peaks. How this is best done with minimum signal distortion is not resolved here, however, the gapped difference operator is the best design yet evaluated. Any distortion introduced by the filter can be effectively removed after array processing.

The improvement in threshold S/N reflects the decrease in the detection threshold for reliable detection of known events. Since we look for failures along one-minute of data, this implies a false alarm probability threshold of about 0.02. One-minute of record contains approximately 50 cells in which a failure can occur, and the threshold can be taken as the .5 probability level for at least one failure in the set. From this, assuming that an occurrence is equally likely in each cell, the probability of a false alarm of .02 is easily derived.

The improvement in S/N ratio is probably a better gauge of performance for input to array processors. For any array processor to work well, the channels must appear similar under signal, and the gain in S/N ratio would appear as a more reasonable measure of this attribute than the change in threshold for reliable detection.

LIST OF FIGURES

Figure No.

1 Noise Power Spectrum

2 Low Frequency Signal

3 Low Frequency Signal - High Pass Filter

4 Low Frequency Signal - Second Difference Filter

5 High Frequency Signal

6 High Frequency Signal - High Pass Filter

7 High Frequency Signal - Second Difference Filter

Table 1 Unfiltered Data

Table 2 High Pass Filtered Data

Table 3 Band Pass Filtered Data Second Difference Filter

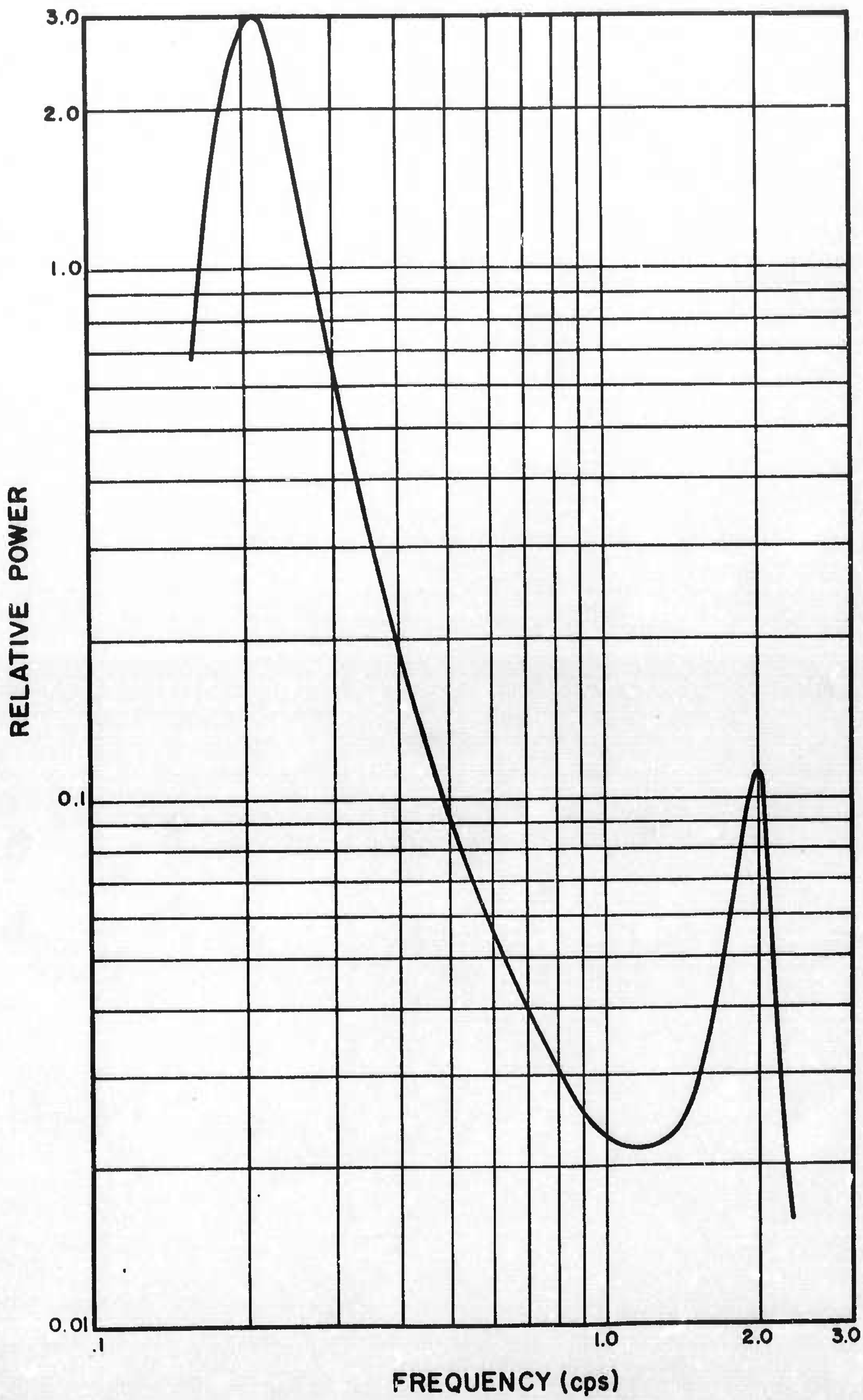

Figure 1. Noise Power Spectrum

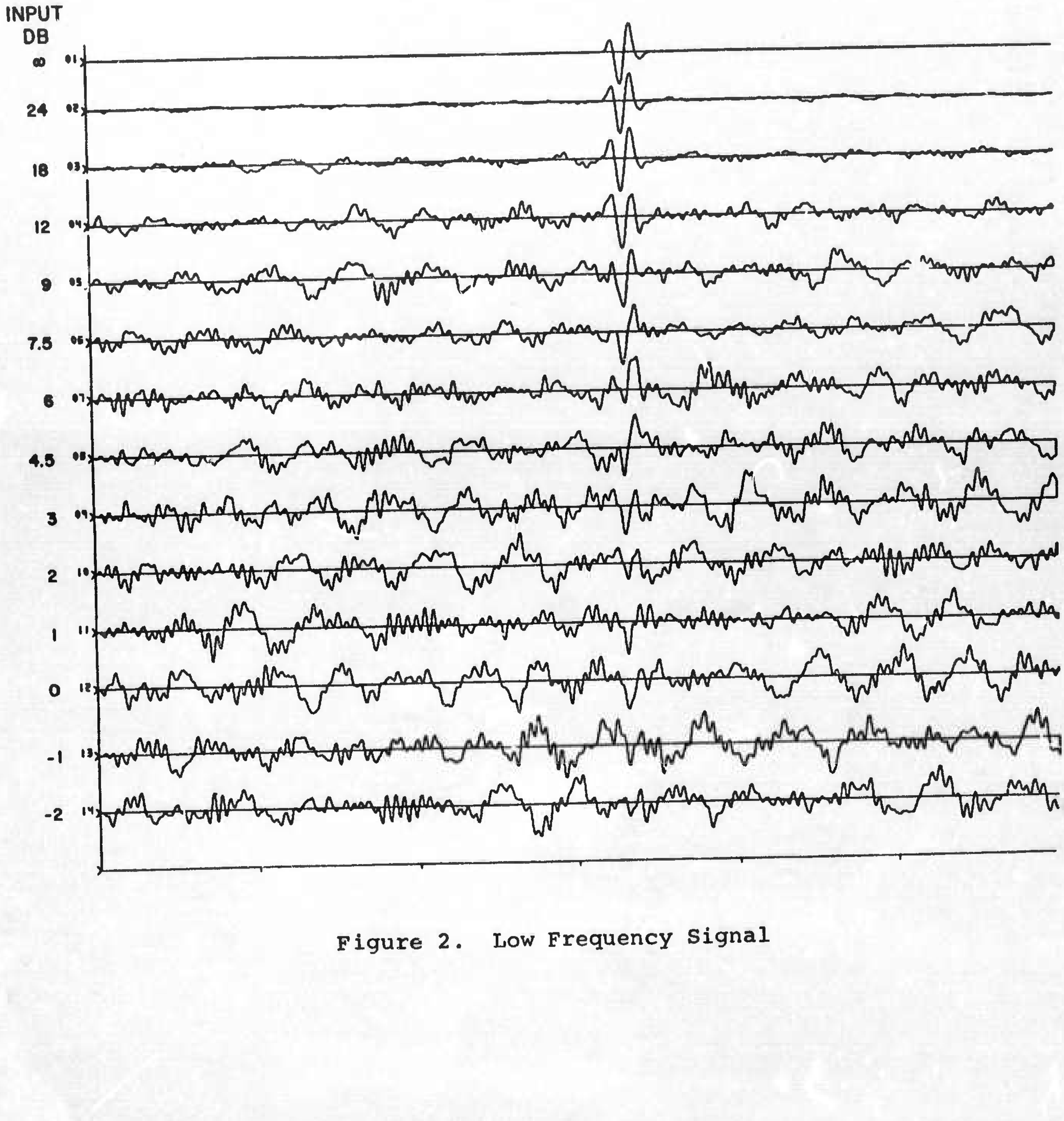

Figure 2. Low Frequency Signal

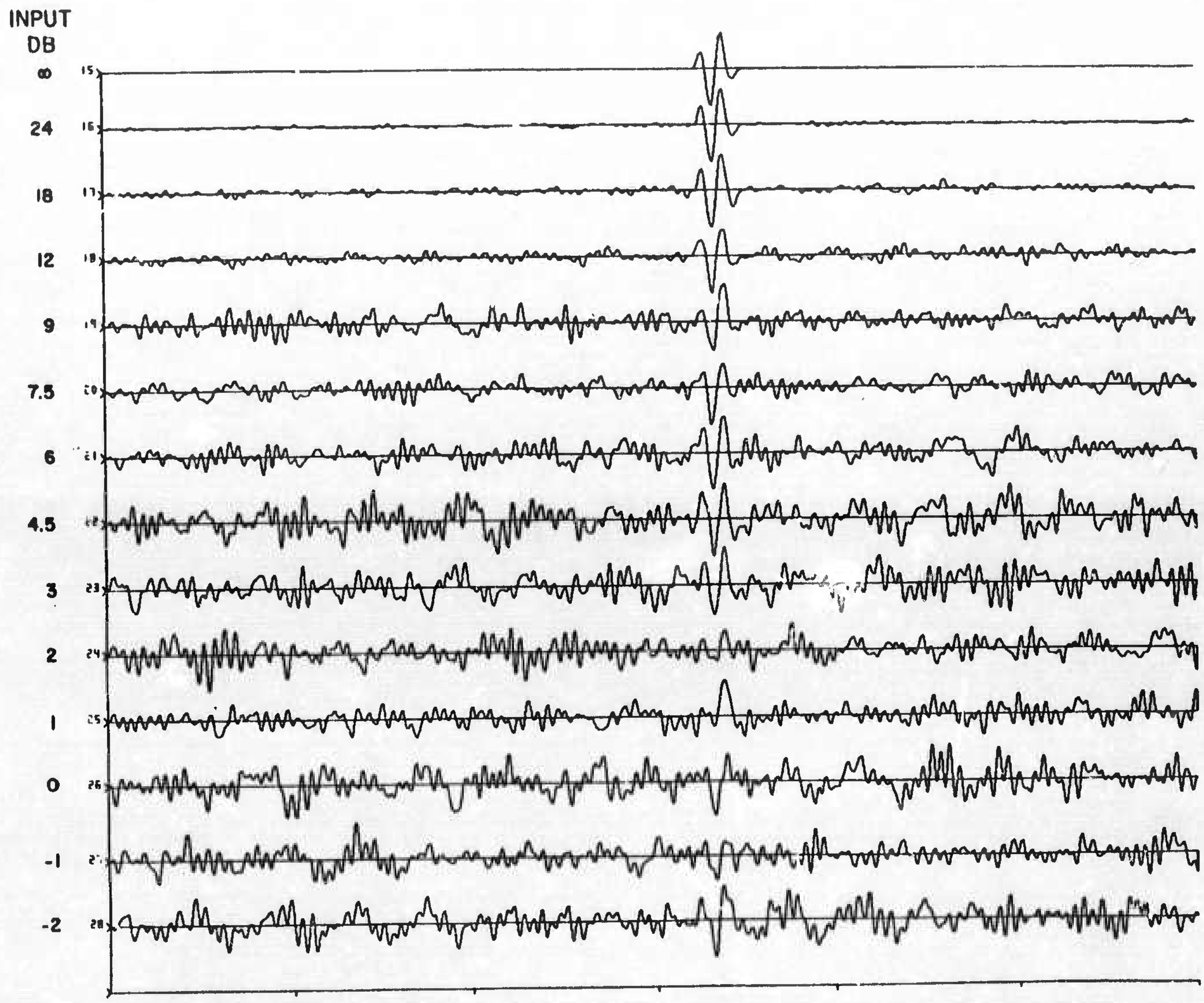

Figure 3. Low Frequency Signal - High Pass Filter

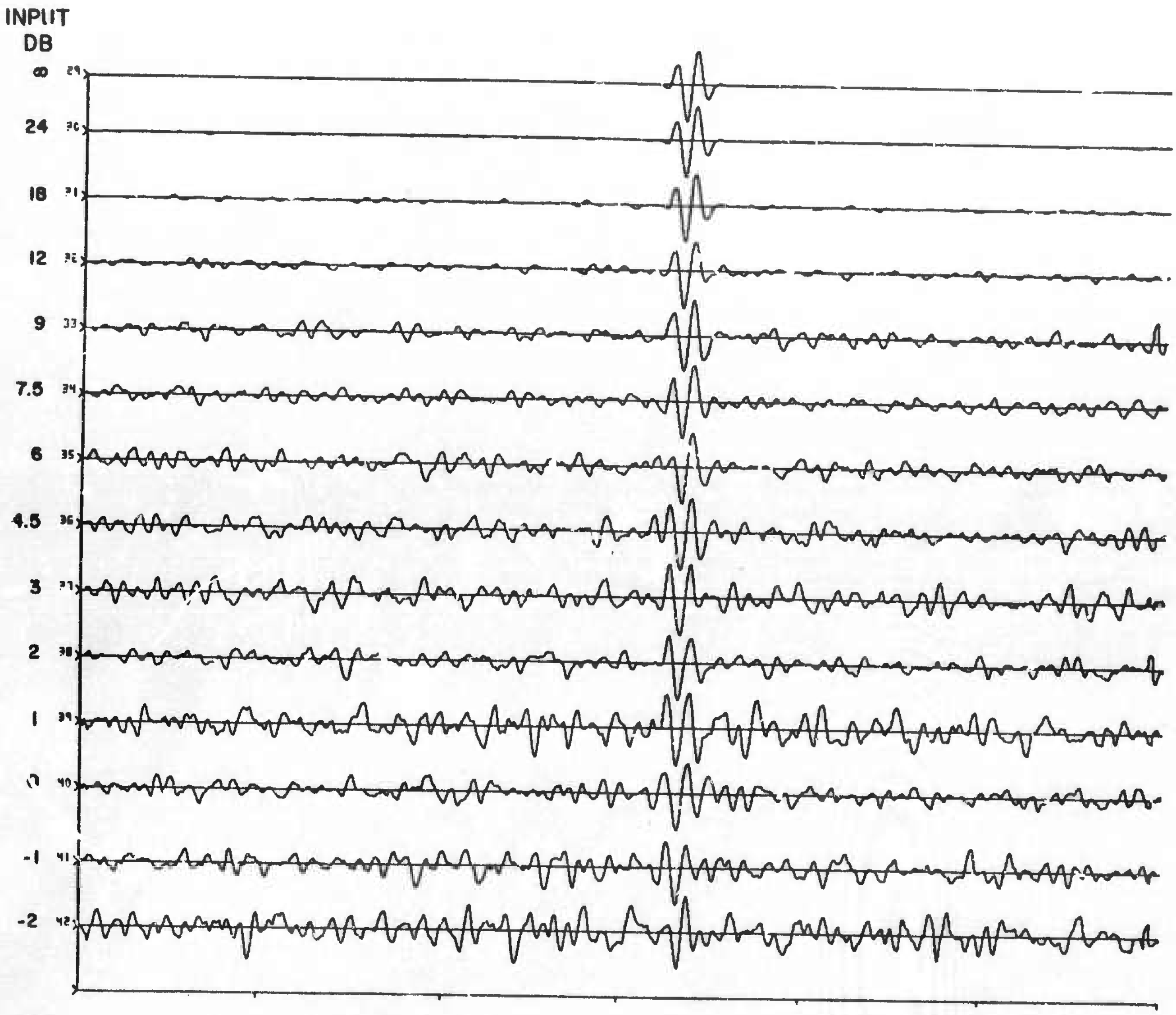

Figure 4. Low Frequency Signal - Second Difference Filter

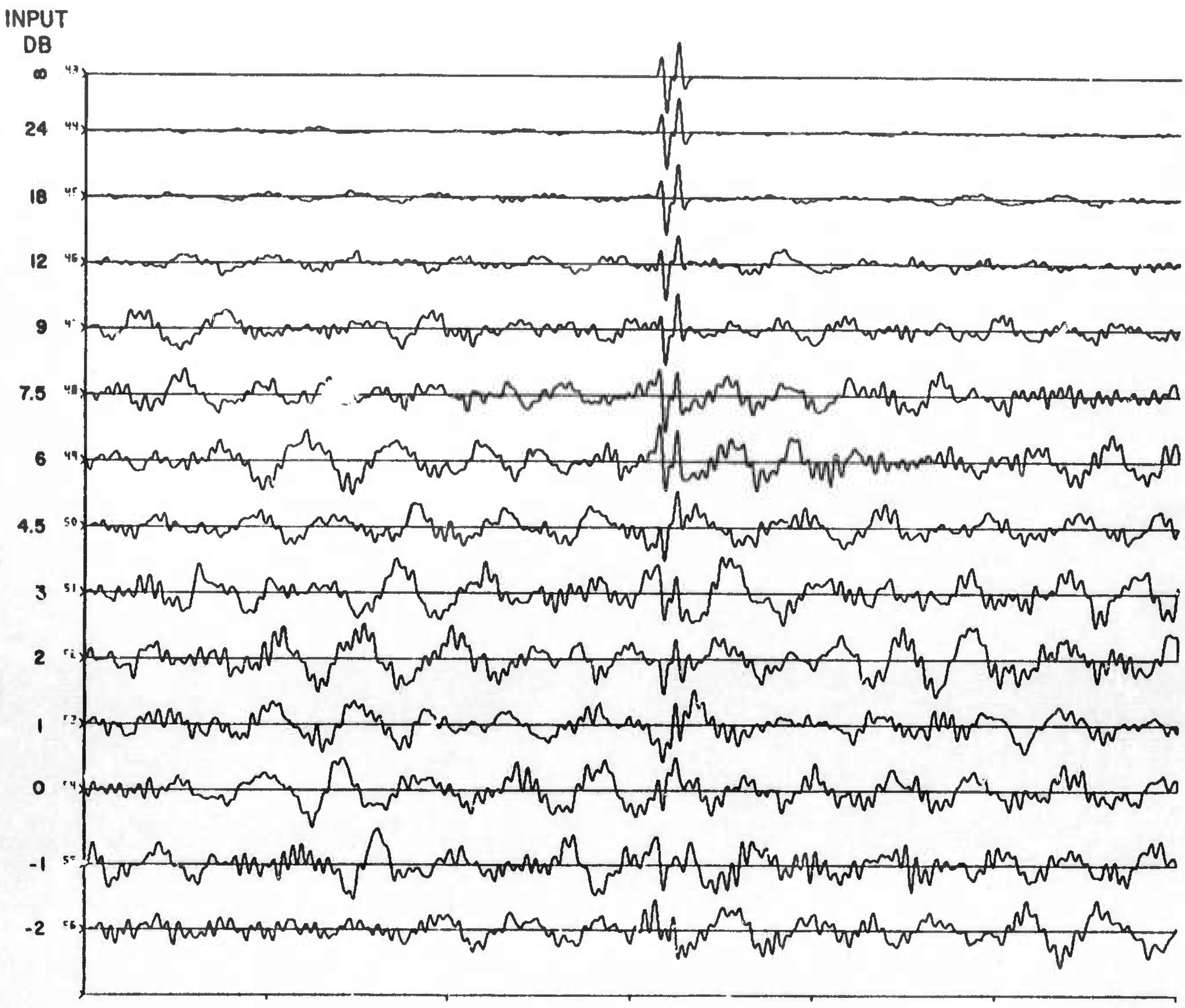

Figure 5. High Frequency Signal

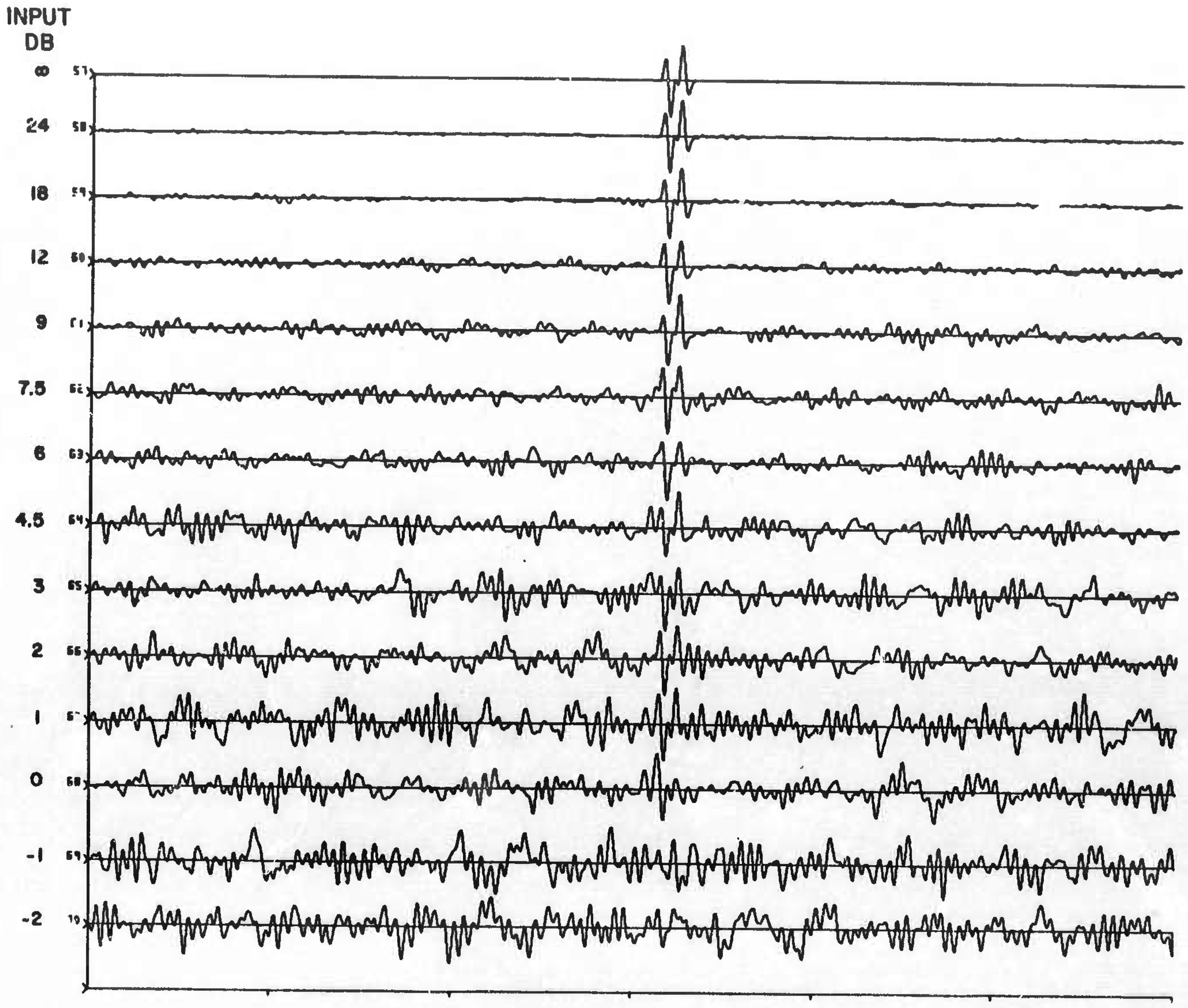

Figure 6. High Frequency Signal - High Pass Filter

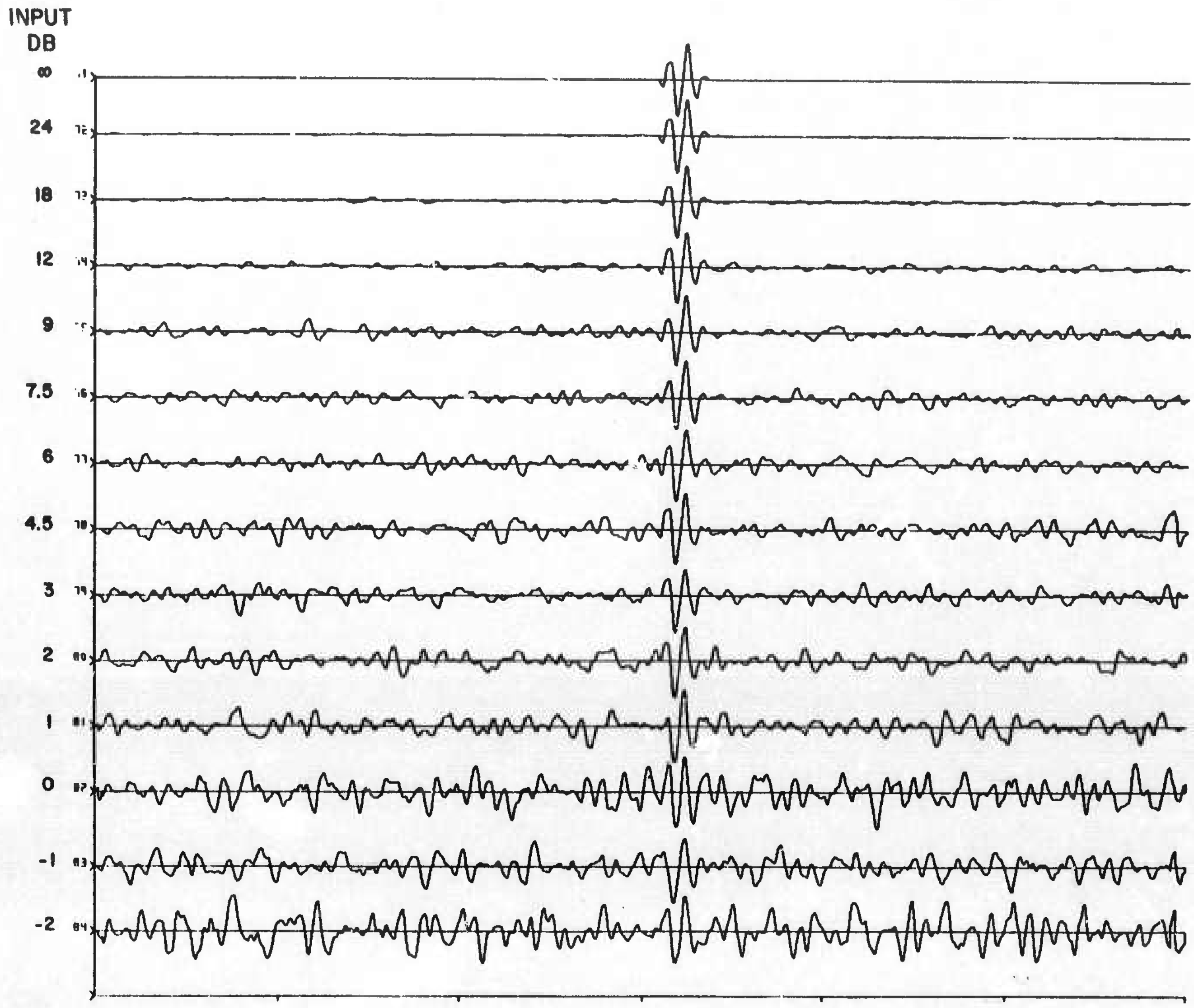

Figure 7. High Frequency Signal - Second Difference Filter

ANALYSIS OF PERFORMANCE

LOW FREQUENCY SIGNAL						HIGH FREQUENCY SIGNAL					
INPUT S/N (DB)	OUTPUT PEAK (DB)	95% C.L.	OUTPUT S/N (DB)	95% C.L.	DETECTION SCORE	INPUT S/N (DB)	OUTPUT PEAK (DB)	95% C.L.	OUTPUT S/N (DB)	95% C.L.	DETECTION SCORE
24	18.1	3.6			10	24	20.8	4.6			10
18	12.5	3.0			10	18	14.4	3.3			10
12	6.8	3.9			10	12	8.5	3.8			10
9	3.7	3.1			10	9	6.0	2.8			10
7.5	5.2	3.4			10	7.5	5.1	4.3			10
6					8	6					6
4.5					3	4.5					5
3					2	3					2
2					2	2					6
1					2	1					3
0					1	0					4
-1					1	-1					1
-2					1	-2					2

Table 1. Unfiltered data

ANALYSIS OF PERFORMANCE

LOW FREQUENCY SIGNAL						HIGH FREQUENCY SIGNAL					
INPUT S/N (DB)	OUTPUT PEAK (DB)	95% C.L.	OUTPUT S/N (DB)	95% C.L.	DETECTION SCORE	INPUT S/N (DB)	OUTPUT PEAK (DB)	95% C.L.	OUTPUT S/N (DB)	95% C.L.	DETECTION SCORE
24	20.9	2.4	27.3	1.8	10	24	24.4	3.3	29.5	2.8	10
18	15.3	2.6	21.5	1.7	10	18	18.3	3.4	22.9	1.6	10
12	10.2	4.0	15.9	1.7	10	12	12.1	4.3	16.4	1.6	10
9	6.6	4.4	13.0	2.5	10	9	9.2	2.5	13.9	1.8	10
7.5	6.5	2.4	10.8	0.8	10	7.5	8.7	3.6	12.1	2.2	10
6	4.3	3.9	10.1	1.8	10	6	6.1	2.7	11.0	2.6	10
4.5			8.2	1.8	9	4.5	4.8	3.9	8.9	1.8	10
3			6.4	2.3	6	3			7.4	1.6	7
2			5.6	1.4	8	2			6.4	1.6	7
1			4.7	1.6	6	1			6.0	2.8	8
0			3.6	1.6	3	0			4.3	2.8	5
-1			2.5	2.7	4	-1			3.2	2.2	3
-2			1.6	2.3	2	-2			2.2	2.9	5

Table 2. High pass filtered data

ANALYSIS OF PERFORMANCE

LOW FREQUENCY SIGNAL						HIGH FREQUENCY SIGNAL					
INPUT S/N (DB)	OUTPUT PEAK (DB)	95% C.L.	OUTPUT S/N (DB)	95% C.L.	DETECTION SCORE	INPUT S/N (DB)	OUTPUT PEAK (DB)	95% C.L.	OUTPUT S/N (DB)	95% C.L.	DETECTION SCORE
24	26.6	3.2	32.5	2.8	10	24	27.0	1.4	33.6	3.0	10
18	20.5	2.3	26.5	2.3	10	18	20.9	4.3	26.6	3.1	10
12	14.5	3.3	20.8	3.0	10	12	14.6	3.3	20.1	1.6	10
9	11.4	5.3	17.7	3.0	10	9	11.7	3.4	18.1	2.4	10
7.5	10.5	2.9	15.8	2.3	10	7.5	11.4	4.6	16.3	2.9	10
6	8.9	3.5	15.1	2.7	10	6	9.2	3.4	15.0	2.7	10
4.5	7.2	2.4	13.1	1.9	10	4.5	7.3	5.1	13.0	2.8	10
3	5.1	5.3	11.2	1.8	10	3	6.4	4.2	11.2	1.7	10
2	4.9	5.7	10.8	1.8	10	2	5.2	4.8	10.1	2.3	10
1	5.4	3.8	10.4	1.5	10	1	4.8	5.5	10.1	3.1	10
0	4.2	4.8	10.3	1.9	10	0	4.1	4.9	8.4	3.4	10
-1			9.0	1.9	7	-1			7.0	2.8	7
-2			7.5	2.3	7	-2			6.3	2.4	6

Table 3. Band pass filtered data,
second difference filter

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) TELEDYNE, INC. ALEXANDRIA, VIRGINIA 22314	2a REPORT SECURITY CLASSIFICATION Unclassified 2b GROUP -----

3. REPORT TITLE

DESIGN, TEST AND EVALUATION OF PRE-SET BANDPASS FILTERS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Scientific Report

5. AUTHOR(S) (Last name, first name, initial)

Sax, R. L.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
30 March 1967	23	0

8a. CONTRACT OR GRANT NO. F 33657-67-C-1313 b. PROJECT NO. VELA T/6702 c. ARPA Order No. 624 d. ARPA Program Code No. 5810	9a. ORIGINATOR'S REPORT NUMBER(S) SDL Report No. 176 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) -----

10. AVAILABILITY/LIMITATION NOTICES
This document is subject to special export controls and each transmittal to foreign governments or foreign national may be made only with prior approval of Chief, AFTAC.

11. SUPPLEMENTARY NOTES -----	12. SPONSORING MILITARY ACTIVITY Advanced Research Projects Agency Nuclear Test Detection Office Washington, D. C.

13. ABSTRACT

Using a known signal added to Gaussian noise, we evaluate the performance of several bandpass filters. The results are about the same as previous exercises carried out on a real data. The gain in threshold for reliable detection and gain in S/N ratio is approximately 8-9 db for a bandpass filter which suppresses both the .2 cops and 2 cps peaks but considerably less if a strong 2 cps peak is not suppressed.

DD FORM 1 JAN 64 1473

Unclassified
Security Classification

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Design						
Evaluation						
Bandpass Filters						
Teleseismic Signal						
Noise						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.